Adapting the Dragonfly Biotic Index to a katydid (Tettigoniidae) rapid assessment technique: case study of a biodiversity hotspot, the Cape Floristic Region, South Africa

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Abstract

Global biodiversity faces many challenges, with the conservation of invertebrates among these. South Africa is megadiverse and has three global biodiversity hotspots. The country also employs two invertebrate-based rapid assessment techniques to evaluate habitat quality of freshwater ecosystems. While grasshoppers (Acrididae) are known indicators of terrestrial habitats, katydids (Tettigoniidae) could be as well. Here, we adapt a South African freshwater invertebrate-based rapid assessment method, the Dragonfly Biotic Index (DBI), for the terrestrial katydid assemblage, and propose a new assessment approach using katydids: the Katydid Biotic Index (KBI). KBI assigns each katydid species a score based on a combination of: 1) IUCN Red List status, 2) geographic distribution, and 3) life history traits (which consist of mobility and trophic level). This means that the rarer, more localized, specialized and threatened katydid species receive the highest score, and the common, geographically widespread and Least Concern species the lowest. As a case study, we calculated KBI across one of South Africa's global biodiversity hotspots, the Cape Floristic Region (CFR). We then correlated KBI/Site scores of individual ecosystems with their ecosystem threat scores. The CFR's katydid assemblage did not differ significantly from that of the overall South African katydid assemblage in terms of its species traits, threat statuses, or distribution among tettigoniid subfamilies. Likewise, KBI/Site scores did not differ significantly among ecosystem threat statuses. This may be explained by the coarse spatial scale of this study or by the lack of specialization of the CFR katydid assemblage. Nevertheless, the KBI holds promise as it is a relatively simple and non-invasive technique for taking invertebrate species composition into account in an assessment of habitat quality. In regions where katydid assemblages are well-known, acoustic surveys and KBI may provide an efficient means for assessing habitats.

Key words

conservation, IUCN Red-List, life history, species traits, ecosystem threat

Introduction

Global biodiversity is facing many challenges, resulting in the extinction of species at rates estimated to be 100 to 1000 times faster than the background extinction rate (Rockström et al. 2009). Biodiversity is often measured, or assessed, to guide conservation planning. These assessments involve the measurement of various vertebrate or plant taxa. Although invertebrates are often not included in these assessments owing to their high numbers of species, it is sometimes assumed that due to the great numbers of insect-plant interactions that insect diversity may mirror that of the plants (Myers et al. 2000). Also, biodiversity assessments usually overlook species-specific information, so ignoring the intrinsic value of each species, and compromising the economic viability and conservation value of biodiversity assessments (Samways 2002).

South Africa currently employs two robust and rapid biodiversity assessment methods targeting freshwater and riparian habitats: the South African Scoring System (SASS) (Dickens and Graham 2002) and the Dragonfly Biotic Index (DBI) (Samways and Simaika 2016). Both of these methods are simple yet effective ways in which stream condition can be assessed based on the resident aquatic larvae of invertebrates (SASS) or on the adult dragonfly assemblages (DBI). The DBI uses three sub-indices to indicate the quality of a freshwater system: geographical distribution, habitat sensitivity and Red List status of each species at a focal locality. Based on these three sub-indices, each species is individually assessed and assigned a score of 0 to 9. The higher a species score, the higher the sensitivity of the species, the lower its tolerance to habitat disturbance, and the more threatened it is. This results in dragonfly assemblages being directly comparable in terms of their conservation value and allows for the ranking of different habitats according to their level of disturbance (Samways and Simaika 2016).

Grasshoppers (Orthoptera: Acrididae) in South Africa are a good bioindicator group within the grassland ecosystems (Bazelet and Samways 2011a, b) as well as the Grasshopper Conservation Index (GCI) having been developed within the Cape Floristic Region (CFR) (Matenaar et al. 2015). However, katydids (Orthoptera: Tettigoniidae) have not yet been explored in the region, and could potentially also be good biological indicators, especially in more woody environments. There are an estimated 169 katydid species in South Africa and, of these, two thirds are thought to be endemic to the country (Picker et al. 2004). So far, 129 species have been described and, as of December 2014, the threat statuses of these species have been assessed and uploaded onto the IUCN Red List (Bazelet et al. 2016). Coupled with the threat statuses, a

wealth of coarse-scale additional information is available, such as estimates of species distributions and life history information. In-depth studies on the biology of individual species are almost entirely lacking, but confident predictions can be made on the basis of trends among species and within higher taxa.

Most notably, mature male katydids produce characteristic species-specific songs enabling non-invasive species detection in an environment by listening alone (Bailey and Rentz 1990). Combined, these characteristics make katydids an attractive taxon upon which an acoustic rapid assessment method could be based for assessing the quality of terrestrial habitats in South Africa (Grant and Samways 2016).

Rapid assessment techniques are vital tools for detecting biodiversity, particularly in areas which have high species diversity and/or experience extreme threat, such as the biodiversity hotspots (Myers et al. 2000, Alonso et al. 2011). Global biodiversity is not homogenous in its distribution (Gaston 2000), with biodiversity hotspots covering only 2% of Earth's surface. Yet 50% of all plant species and 42% of terrestrial vertebrate species exist in this 2% of land (Mittermeier et al. 2004). These "traditional" biodiversity hotspots do not take into account invertebrate diversity, as it was assumed that insect diversity mirrors that of the plants based on the high numbers of observed insect-plant interactions (Orme et al. 2005). The CFR, one of three biodiversity hotspots in mega-diverse South Africa (Mittermeier et al. 2004), is an example of insect diversity mirroring plant diversity (Procheş and Cowling 2006), although these patterns do vary among insect taxa, with some having significantly higher diversity than others (Wright and Samways 1998, Procheş and Cowling 2006).

Here, a new biodiversity assessment method that employs katydids for monitoring terrestrial habitat quality based on an adaptation of the DBI is outlined. The calculation of the Katydid Biotic Index (KBI) is described, and a subset of museum records is used to conduct a case study to illustrate the efficacy of the KBI for assessing biodiversity and habitat quality across a biodiversity hotspot, the CFR, in South Africa. Ultimately, the KBI is evaluated with regards to its possible use in highlighting ecosystems in need of conservation action.

Materials and methods

Data collection.— In 2014, the Red List threat statuses of 133 katydid species were assessed using records obtained from the MANTIS database (Naskrecki 2008). Geographical ranges of species and species endemism were calculated using the collection localities of the records. Published taxonomic descriptions as well as expert knowledge were used to assess various life history traits of the individual species (Rentz 1988, Naskrecki et al. 2008, Naskrecki and Bazelet 2009, 2012) [see Bazelet et al. (2016) for methods description].

Development of the Katydid Biotic Index.— The KBI allows for individual species to be ranked and compared. Based on similar criteria to that of the DBI, katydids were assessed based on three sub-indices: 1) Red List Status, 2) geographical distribution, and 3) life history traits (in which the mobility and the trophic level at which the species feed are scored on the basis of objective criteria, these two values are then summed, and scored accordingly). Each sub-index is scored from 0 to 3, with the life history category being a combination of individual scores for mobility and trophic level. These sub-indices are added together to give the KBI score for a species. These species KBI scores range from 0 for a widespread, habitat tolerant, Least Concern (LC) species to 9 for a narrow-range, highly habitat sensitive and Red Listed species (Table 1; Bazelet et al. 2016).

The sum of the scores in any specified region or at any particular site is the total KBI score. When the site score is divided by the number of species recorded, it gives the KBI/Site score. The KBI/Site score is thus an average value calculated from all the individual KBI species scores, and allows for the ranking of sites based on their katydid assemblages.

Katydids in the Cape Floristic Region.— Globally renowned for its botanical diversity, the CFR includes 122 different vegetation types or ecosystems (Government Gazette 2011) and covers <4% of southern Africa or an area of ±90 000 km^2. Within this relatively small area, an estimated 8640 species of plants occur, of which

Table 1. Katydid Biotic Index calculation method.

Species Score	Threat (T)	Distribution (D)	Life History Traits (LH)†		
			Mobility (M)	*Trophic Level (Tr)*	*M+Tr Sum*
0	LC	Very common: > 75% coverage of SA and sA	Fully-flighted	Omnivorous	0
1	VU	Localized across a wide area in SA, and localized or common in sA: > 66% in SA and > 66% sA -OR- Very common in 1-3 provinces of SA and localized or common in sA: 0 - 33% SA and >66% sA	Only one sex flighted -OR- One or both sexes partially flighted	Predatory	1–2
2	EN	National SA endemic confined to 3 or more provinces: > 33% SA -OR- Widespread in sA but marginal and very rare in SA < 33% SA and > 66% sA	Flightless	Herbivorous, polyphagous	3
3	CR	Endemic or near-endemic and confined to only 1 or 2 SA provinces < 33% in SA alone		Herbivorous, monophagous	4–5

SA=South Africa, Lesotho, and Swaziland and sA = southern Africa (South Africa, Lesotho, Swaziland, Namibia, Botswana and Zimbabwe).

† To calculate LH score, M (range 0 - 2) + Tr (range 0 -3) are summed. The sum is assigned a logical species score.

65% are considered endemic to the CFR. The total number of species within the CFR is disproportionate to its small size as the observed number of species is comparable to that of tropical regions (Goldblatt and Manning 2002).

A subset of geo-referenced katydid collection localities (n = 207 and accurate to eight decimal places) for the CFR was extracted from the MANTIS database (Naskrecki 2008; see supplementary material of Bazelet et al. (2016) for raw data records). Using QGIS (Quantum GIS Development Team 2015) katydid records were associated with the CFR ecosystem in which they were found, the threat statuses of the individual ecosystems was available in the list of threatened terrestrial ecosystems (available through the Biodiversity GIS programme of the South African National Biodiversity Institute, map scale was 1:250 000). Duplicate records of the same species were removed from the ecosystems so that there was only one record per species per ecosystem. Average KBI values for each individual ecosystem were calculated. The threat scores and average KBI scores were then mapped using QGIS.

Statistical analysis.— A Chi-square contingency table was used to determine whether the distribution of species among threat statuses and level of endemism were significantly correlated for South African and CFR katydid species. A Kruskal-Wallis test in R (R Development Core Team 2013) was used to assess differences in mean KBI scores of the katydid assemblages of the individual ecosystems and the threat categories to which the ecosystems belong (LC, VU, EN and CR). This was done across the entire CFR , separately for the ecosystems on the eastern seaboard and a one-way ANOVA was conducted for those on the western seaboard. Kruskal-Wallis was selected as it is suitable for non-parametric data, as KBI scores were not normally distributed (Shapiro-Wilk's W = 0.95, $p < 0.001$). Post-hoc Nemenyi-Tests were then conducted using the package PMCMR in R (Pohlert 2015) to assess pairwise differences among katydid threat statuses, ecosystem threat status and average KBI. After mapping the threat scores and average KBI scores of the ecosystems these two maps were then visually assessed in order to identify any emergent patterns.

Results

Of the 133 katydid species which were assessed for IUCN Red List threat status, 16 (12%) were Data Deficient (DD) and were therefore excluded here from further analyses. Across all South African katydid species, over 50% are considered to be LC, while 35% of species were assessed as threatened [Vulnerable (VU), Endangered (EN), or Critically Endangered (CR)]; (Fig. 1A). Within the CFR, of the non-DD species, almost three-quarters (73%) of species are LC, and 27% of species are threatened (Fig. 1B).

The CFR katydids did not differ significantly from all South African katydids in terms of the number of species assigned to each threat status, endemism level, mobility class or trophic level ($\chi^2_{(df=3, =134)} = 0.88$, $p > 0.05$; $\chi^2_{(df=3, =38)} = 0.25$, $p > 0.05$; $\chi^2_{(df=2)} = 0.9$, $p > 0.05$ and $\chi^2_{(df=3)} = 0.07$, $p > 0.05$ respectively; Fig. 1).

Within the total katydid assemblage of South Africa, all species considered to be threatened (VU, EN or CR) were also endemic to the country, this is also true for the CFR katydid species (Fig. 2A, B). Across the CFR, 62% (n = 11) of all species are flightless, and within the entire South African assemblage 60% (n = 11) are flightless (Fig. 1H, G). No South African flighted species was assessed as either EN or CR (Fig. 2C), and all flighted species in the CFR were assessed to be LC (Fig. 2D). Among the South African katydid assemblage, species with varying trophic levels were evenly spread across the threat status categories (Fig. 2E). However, within the CFR katydid assemblage, all omnivorous species were classified as LC, while 25% of species (n = 8) were monophagous herbivores and these were relatively more prevalent in the threat classes (VU, EN and CR) than in LC (Fig. 2F).

The distribution of species in each subfamily maintained similar patterns in the CFR as in South Africa as a whole, with Phaneropterinae the most abundant subfamily overall, and Pseudophyllinae the least common (Fig. 3).

As expected, LC katydids have significantly lower median species-specific KBI scores than the threatened katydids (VU, EN and CR), but interestingly, these do not differ from each other ($\chi^2 = 44.18$, df = 9, $p < 0.05$). There were no significant differences in the mean KBI scores among the ecosystem threat status categories ($\chi^2 = 3.28$, df = 3, $p > 0.05$; Fig. 4). Although not significantly different (F = 0.91, df = 33, $p > 0.05$), through visual inspection, in the western seaboard section of the CFR, there appears to be a slight but non-significant inverse correlation between the KBI score with ecosystem threat status, such that the lower the KBI score, the more threatened the ecosystem threat status. In the eastern seaboard section of the CFR, this relationship is not evident ($\chi^2 = 0.79$, df = 3, $p > 0.05$; Fig. 5).

Discussion

Although no significant differences were observed among the ecosystem threat statuses in terms of their KBI/Site values (i.e. average KBI value), the aim was rather to show how the KBI could be employed in the future once more thorough sampling has been conducted. When mapped, patterns do start to emerge in KBI/Site values among ecosystems. Ecosystems with low KBI/Site scores (mean KBI 0 – 4) tend to be those which are threatened (CR, EN and VU ecosystems) in the western CFR while the LC ecosystems tend to score higher KBI/Site values (mean KBI 5 – 8). This relationship is to be expected, as the more common and less sensitive species will be able to persist in ecosystems that have been transformed from the original state. Whereas the more sensitive and threatened species (those with higher species-specific KBI values) are expected to prefer the natural habitats and not to persist in the transformed systems. However, in the eastern CFR, where the ecosystems appear to be less threatened overall, there seems to be little correlation between the threat status of the ecosystems and their KBI/Site values. The LC ecosystems score relatively low KBI/Site values, between 0 and 4. These discrepancies could be due to numerous factors.

Among the possible explanations for the lack of correlation between ecosystem threat status and KBI/Site value, the small sample size is the most likely. With only 162 unique katydid records being present in 54 of the 122 CFR ecosystems (or 44% of ecosystems), the area is under-sampled. Furthermore, the scale of this study was very coarse and the KBI/Site values were calculated according to ecosystem threat polygons which is not a relevant biological spatial scale for katydids. Future work would need to determine the spatial scale at which the KBI/Site would be an accurate measure, as has been discussed for the DBI (Samways and Simaika 2016).

Furthermore, the CFR is an arid biome characterized by a matrix of agriculturally transformed landscapes and the native fynbos vegetation, which is characterized by evergreen plants in the Ericaceae, Restionaceae and Proteaceae families. Large trees are naturally almost absent from the CFR (Rebelo et al. 2006). In turn, katydids are known to be most diverse and abundant in tropical forest habitats and some subfamilies, like the Pseudophyllinae, show a strong degree of adapta-

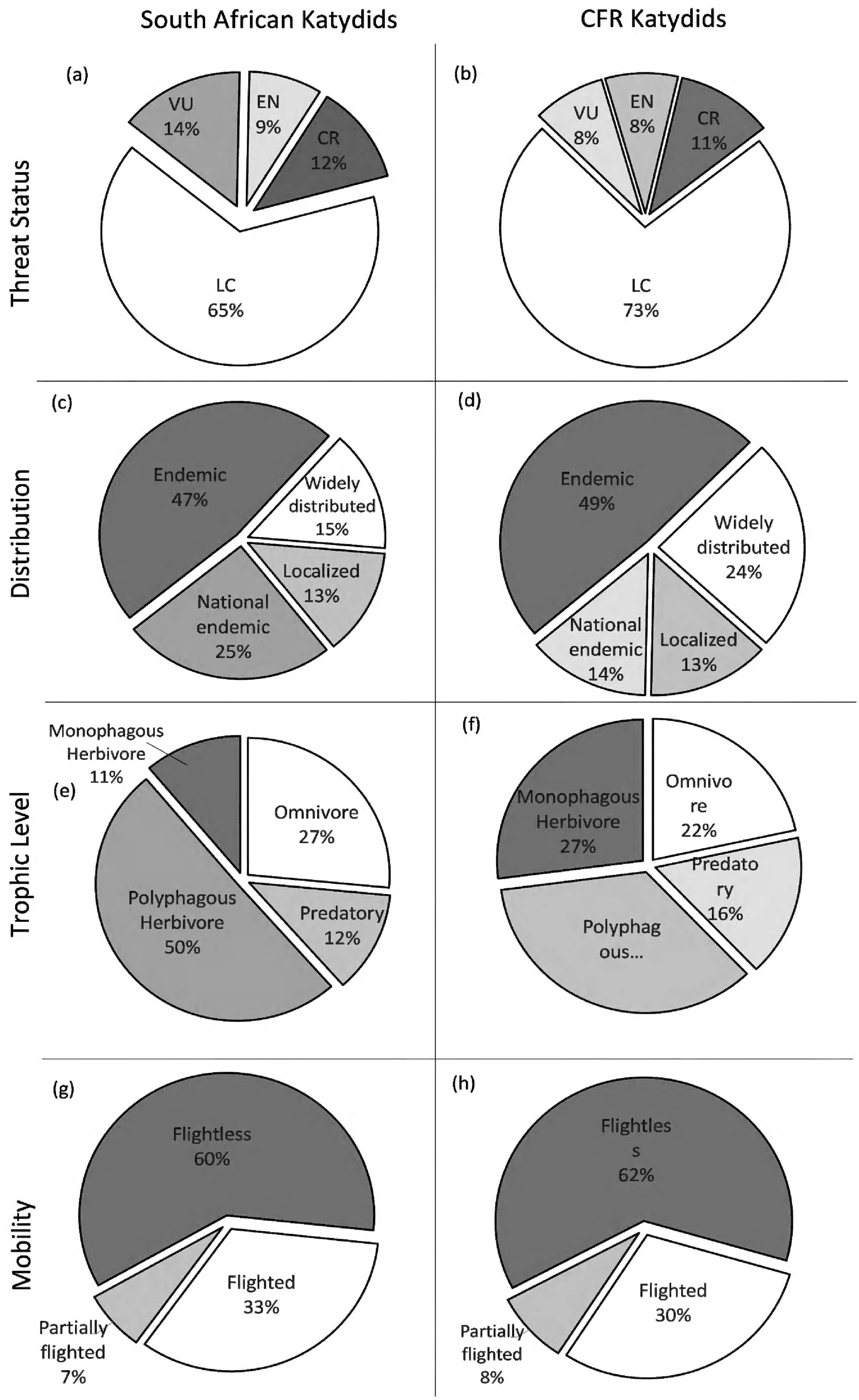

Figure 1. Proportion of South African (**A, C, E, G**) and Cape Floristic Region (**B, D, F, H**) katydid assemblages as characterised by the KBI assessment criteria (Threat Status, Distribution, Trophic level and Mobility).

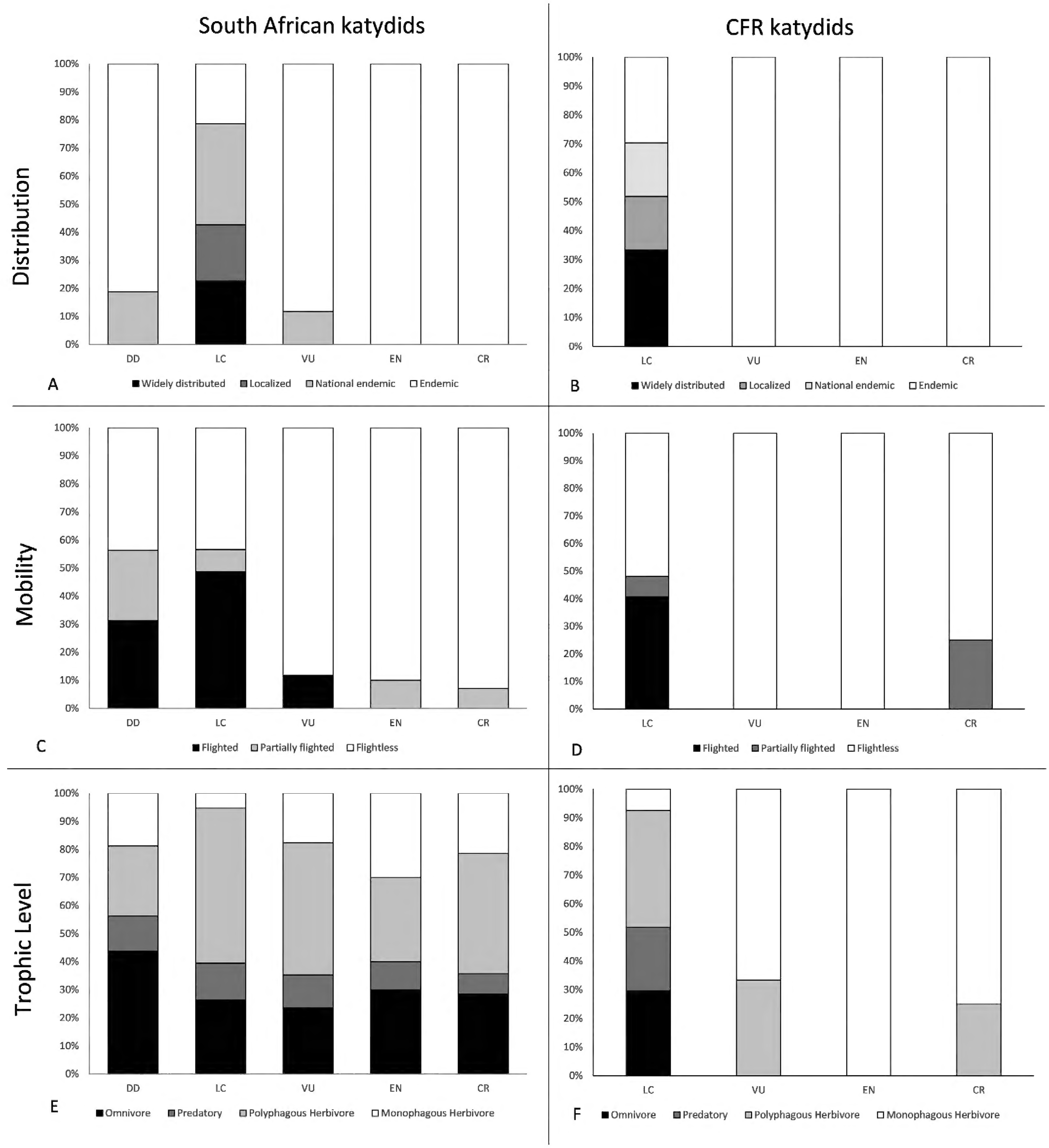

Figure 2. Composition of South African (**A, C, E**) and Cape Floristic Region (**B, D, F**) katydid assemblages as characterised by their distribution (**A, B**), mobility (**C, D**), and trophic level (**E, F**) relative to their IUCN threat status.

tion to tree environments, often bearing a strong cryptic resemblance to their tree habitats. Understandably, Pseudophyllinae are extremely rare in the CFR and in South Africa in general, of which only 1% is native forest habitat (Mucina and Rutherford 2006).

South African katydids are relatively well-documented (Naskrecki, unpublished data). Information regarding the ecology and habitat requirements of the species is relatively well-known, and where information is lacking, it is possible to infer a species' biological characteristics based on well-documented related species. Indeed, most species could be assessed for the IUCN's Red List (Bazelet et al. 2016). Although some habitats and katydid groups are more diverse than others, katydids are found in nearly

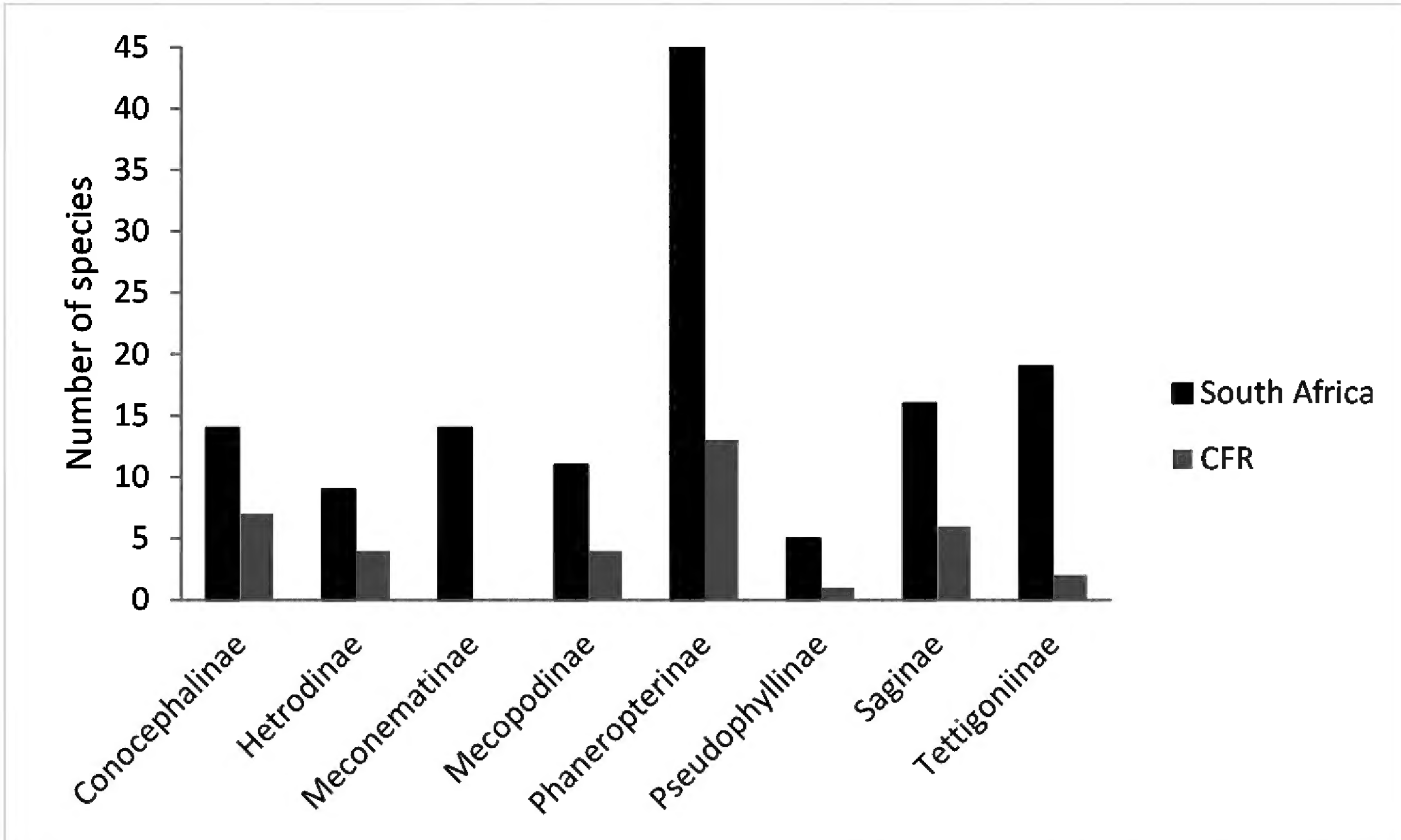

Figure 3. Distribution of South African and Cape Floristic Region katydid species among Tettigoniidae subfamilies.

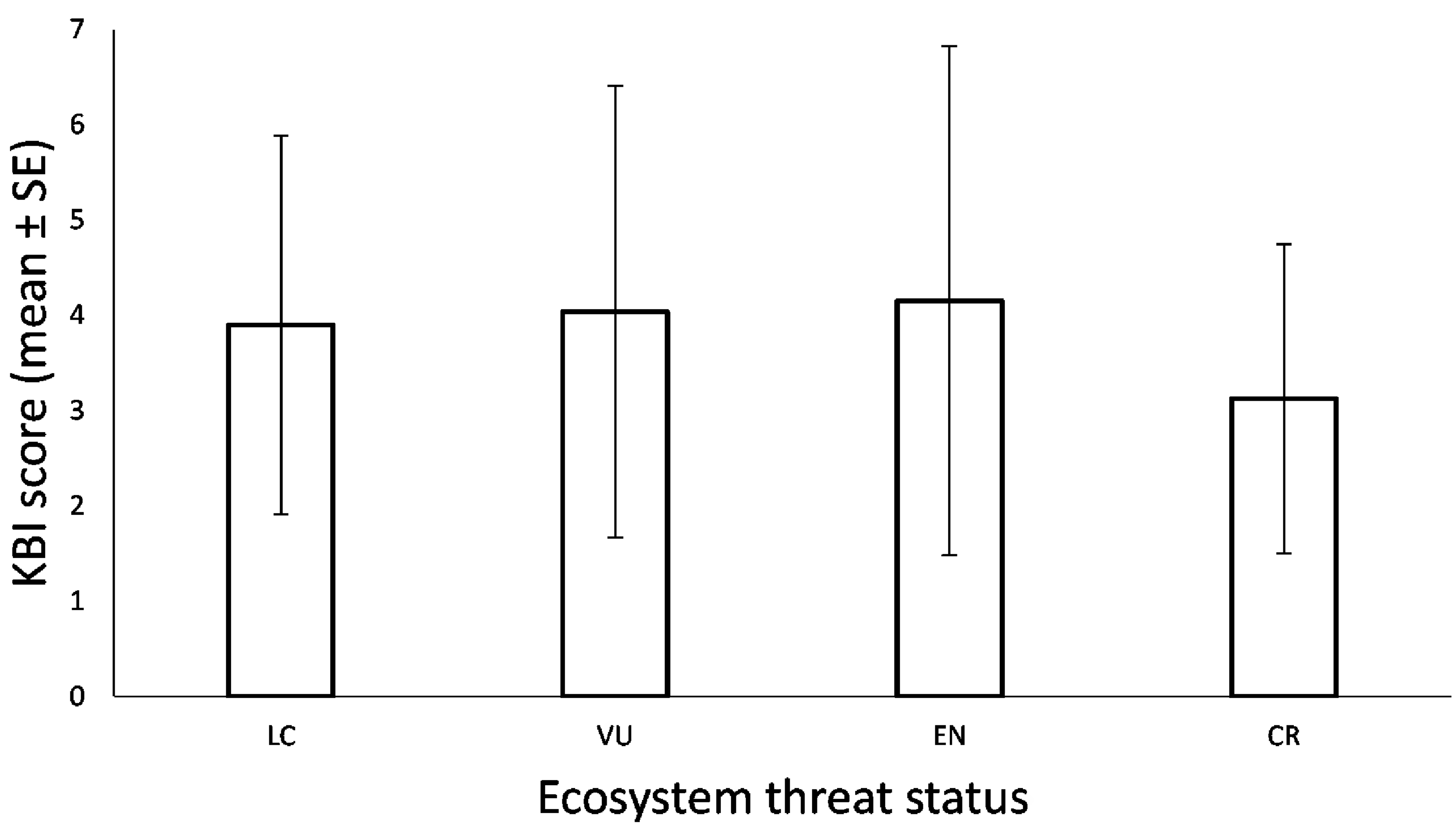

Figure 4. Distribution of Katydid Biotic Index (KBI) among ecosystem threat statuses (mean ± s.e.).

all terrestrial ecosystems in South Africa and thus present themselves as a favourable taxon upon which to base a rapid assessment method.

All threatened South African katydids (VU, EN and CR) are either national endemics or are localised endemic species. One of the weaknesses of the DBI and of the current method is that distribution is taken into account in the Red List assessment (when species are scored according to Criterion B which was the case for almost all katydids) and is then used again for scoring of the KBI. This leads to a potential problem of intercorrelation between two of the three categories of the KBI. The Dragonfly Biotic Index (DBI) is a very powerful assessment tool used in South Africa and is based on the threat status, distribution and sensitivity to habitat change (Samways and Simaika 2016), even here there exist intercorrelations between the distribution and threat status and yet this provides accurate assessments of habitat quality.

Patterns are seen in the effective mobility of a species, with the less mobile species featuring more prominently in the threatened classes. These patterns are also then maintained within the CFR katydids. Katydid traits are shown here to correlate with threat status, thus providing further evidence that the KBI will be an effective way to monitor habitat quality through the resident katydids.

Katydids are known to be highly cryptic as a result of excellent leaf mimicry and, when combined with their predominantly nocturnal habitats, they are notoriously difficult to locate in the

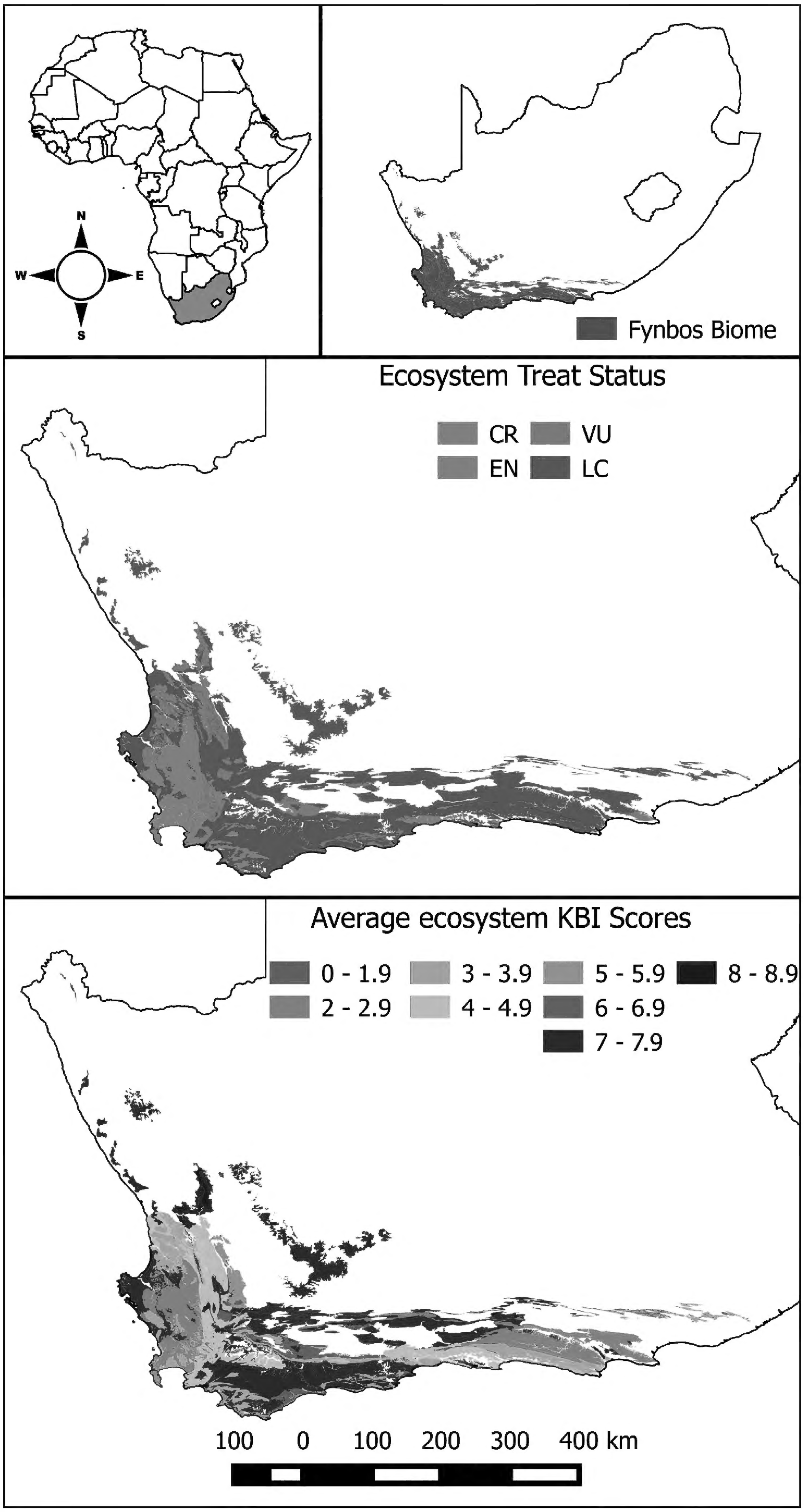

Figure 5. Map of ecosystem threat statuses and the average KBI scores (i.e. KBI/Site) of each ecosystem.

wild. This means that they are not a popular taxon for assessment in comparison with other charismatic invertebrate groups such as dragonflies and butterflies. For this reason, museum records of katydids become a very important source of information. The MANTIS database contains records of all 126 valid species of katydids in South Africa, so allowing for the individual species to be assessed for KBI assessments as accurately as possible.

Although cryptic and difficult to locate, katydids are perhaps best known for the species-specific songs produced by mature adult males (Bailey and Rentz 1990). There has been considerable research into monitoring and tracking of katydid species, as well as other acoustically communicating insects, through acoustic monitoring (Riede 1993, 1998, Diwakar et al. 2007a, Grant and Samways 2016). Acoustic monitoring can be conducted using a variety of techniques, ranging from simple listening exercises (Diwakar et al. 2007b) to complex microphone arrays (Stevenson et al. 2015). In South Africa, acoustic monitoring of katydids is an attractive option as the acoustic environment in which they sing is not such a complex chorus as in tropical forests. The CFR, in particular, has a simple acoustic assemblage, but very complex Mediterranean-type vegetation structure consisting of a majority of thorny and difficult to access bushes and shrubs. This provides ample hiding space for katydids, and increases the need to detect singing individuals.

In view of these conditions, South African katydids can be monitored using inexpensive and simple equipment. A well-trained listener is able to distinguish between the different calls of both katydid and gryllid species (Diwakar et al. 2007b). It is not possible for these listeners to pick up any ultrasonic calls, yet by using a bat detector, inaudible ultrasonic calls can be down-scaled and rendered audible so that real-time identification of katydid species is possible in the field. Although time is required for the listener to learn the various calls, time will be saved in the long-term as, once a reliable voucher collection with associated song library has been constructed, there will be no need to locate the individual insect to correctly identify it. Simple and relatively cheap recorders are also available for long-term deployment, allowing for passive, non-invasive monitoring that, once an operator is well trained, provides an effective way in which to remotely monitor katydid distributions.

Despite a few apparent weaknesses of the KBI, this study aimed to simply determine whether the DBI could be adapted to katydids as it has been proven to be a decidedly powerful tool in similar regions to this study. Further comparisons to existing assessment methods will be required in order to accurately determine the effectiveness of the KBI. As this study relied on museum records only, the "rarity" component of the GCI could not be accurately assessed.

Conclusions

With improved monitoring of katydids, perhaps on a smaller scale and with controlled measuring of environmental parameters, it could be possible to demonstrate the further value of this scoring system as a monitoring technique. This is a preliminary study aimed only to introduce the idea of a rapid assessment method for terrestrial habitats based on katydid song. It has identified some of the advantages of the approach but has emphasized that much more data gathering is required. However, it does appear as if the KBI may be a promising method, particularly for regions where katydids are abundant and diverse, but relatively well-known.

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